PHOTOSYNTHETIC RESPONSE OF SELECTED RED MAPLE CULTIVARS TO LIGHT

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Abstract. Four red maple (*Acer rubrum* L.) cultivars ('Franksred' - Red Sunset™, 'Northwood', 'October Glory', and 'Schlesingeri') grown in containers were evaluated for response to different photosynthetically active radiation (PAR) levels. As PAR increased, there was a linear increase in net photosynthesis (Pn) and transpiration (E) for 'Franksred' and 'October Glory'. In contrast, Pn and E for 'Northwood' and 'Schlesingeri' increased as PAR increased to about 1375 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and 1350 $\mu mol \cdot m^{-2} \cdot s^{-1}$, respectively and declined thereafter. PAR had no relationship to water use efficiency (calculated as Pn/E) for the four cultivars. Mesophyll resistance (r_m) to CO_2 (CI/Pn) decreased linearly as PAR increased for 'October Glory'; but 'Franksred', 'Northwood', and 'Schlesingeri' exhibited a quadratic response to PAR (with estimated lows of 17.61 $cm \cdot sec^{-1}$ at 1600 PAR, and 16.45 $cm \cdot sec^{-1}$ and 16.36 $cm \cdot sec^{-1}$ at 1400 PAR, respectively). The enhanced photosynthetic mechanism for r_m as PAR levels increased suggests that 'October Glory' is the most adapted cultivar of the four selections in this study for high PAR environments. Furthermore, adaptive ranges of red maple cultivars may be predicted during developmental stages by establishing light curves for Pn, E, and r_m.

Inherent differences in the utilization of available photosynthetically active radiation (PAR) is seldom considered when selecting tree cultivars for a given region. Yet, large differences in the quantity of light received during the growing season exist between latitudes even within the United States (Fig. 1). Lack of adequate information regarding adaptability of tree cultivars often leads to the use of trees poorly suited to a region, resulting in high maintenance and removal costs (6). With cultivars there is a certain stability with regard to form, foliage, and growth habit. However, there remains considerable variation among cultivars in regional adaptability. Of recognized red maple cultivars (currently about 55), none have been developed and released as selections originating in the southern portion of their native range (14, 18). Research initiated in 1989 has begun to provide information on growth characteristics and adaptability of selected cultivars and seedlings of red maple (*Acer rubrum* L.) in lower latitudes (17).

The photosynthetic characteristics of a wide range of plants are influenced by the light environment in which they are grown (4). Silver maple (*Acer saccharinum*) seedlings had relatively high rates of net photosynthesis (Pn) over a broad range of photosynthetically active photon flux densities (12). Maximum photosynthetic rates

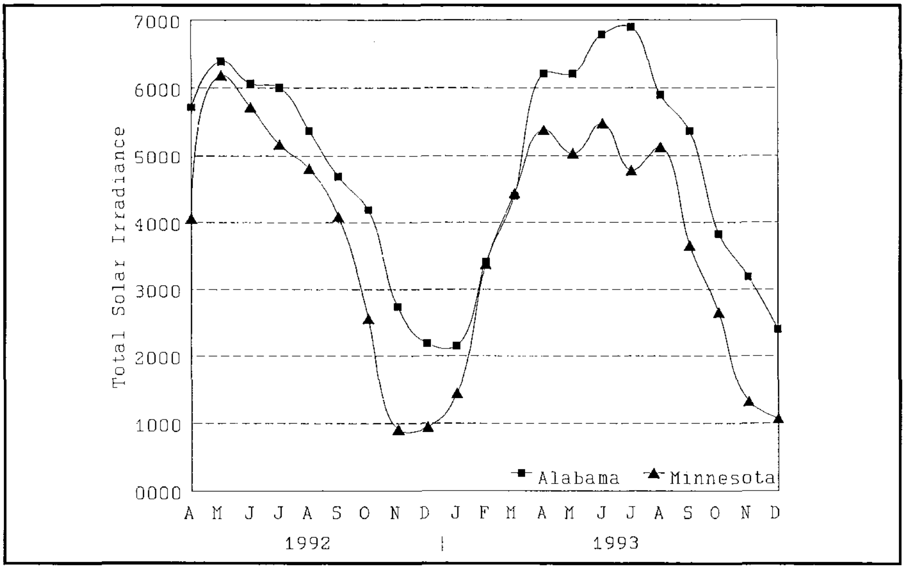

Fig. 1. Monthly average total solar radiation (K↓) in Winton, Minnesota and Auburn, Alabama for 1992 and 1993. Units for irradiance from integrated measurements = Wh m⁻².

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occurred at 1600 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Similar results were found for transpiration. Sugar maples from seed collected along different altitudinal gradients differed in photosynthesis, respiration, and specific leaf weight (9). Light saturation for seedling red maple near 1200 $\mu mol \cdot m^{-2} \cdot s^{-1}$ has been implied (7), however insufficient information is available to make a definitive statement, especially with regard to specific cultivars of red maple.

Red maple cultivars in the Southeast differed in gas exchange capacities, growth rate, fall color, and viability (16). While leaf water potentials were similar for all cultivars throughout the day, net photosynthesis (Pn) for 'Franksred', 'Northwood', 'October Glory', and 'Schlesingeri' differed. Rates of Pn were higher for 'Northwood' and 'Schlesingeri' (selections from more northern latitudes), than for 'Franksred' and 'October Glory' (selections from more southern latitudes) until midday, after which Pn rates for 'Northwood' and 'Schlesingeri' declined while Pn rates for 'Franksred' and 'October Glory' continued to increase. Based on these results, the objective of this study was to determine the gas exchange response of these four selections when exposed to varying PAR levels. This information should provide us with a better understanding of the physiological adaptability of these cultivars to PAR levels typical of lower latitudes.

Materials and Methods

Selections of four cultivars; 'Franksred', 'Northwood', 'October Glory', and 'Schlesingeri' were obtained in March, 1993 from a single nursery source (J. Frank Schmidt and Sons, Inc., Boring, Oregon) as 1.7 meter bare root whips from tissue culture origins. Trees were planted in 56.8 liter containers in a 6:1 (v:v) pinebark/sand media amended with 8.3 $kg \cdot m^{-3}$ 17-7-12 Osmocote (O.M. Scotts Co., Maryville, Ohio), 3.0 $kg \cdot m^{-3}$ dolomitic lime, and 0.9 $kg \cdot m^{-3}$ Micromax (O.M. Scotts Co., Maryville, Ohio). Trees were grown in full sun for 6 months under standard nursery irrigation practices at Auburn University, Alabama (lat. 32° 83' N, long. 85° 30' W, elev. 652'). Selections were arranged in a randomized complete block design with 4 blocks including 3 plants per cultivar per block for a total of 12 trees each. Wooden frames 10 m apart were covered with shade cloth of different light penetration levels to maintain desired treatment effects which were: No shade (average PAR during measurements = 1743 $\mu mol \cdot m^{-2} \cdot s^{-1}$), 25% shade (average PAR during measurements = 1234 $\mu mol \cdot m^{-2} \cdot s^{-1}$), 50% shade (average PAR during measurements = 691 $\mu mol \cdot m^{-2} \cdot s^{-1}$), and 75% shade (average PAR during measurements = 390 $\mu mol \cdot m^{-2} \cdot s^{-1}$). Each block of trees was evaluated under each shade treatment structure following acclimation to each light environment for one-half hour prior to gas exchange measurements (2, 8). Net photosynthesis (Pn), stomatal conductance (Cs), transpiration (E), and internal CO_2 concentration (CI) were measured with a portable photosynthesis system (LICOR 6250, LI-COR Inc., Lincoln, Nebraska, USA) in a closed mode (10). Light levels were monitored with a quantum sensor (Model LI-190, LI-COR, Lincoln, Nebraska) attached to the plexiglass chamber. Three measurements per tree per treatment were taken on single, attached, fully expanded leaves of terminal shoots 4 - 5 nodes from the tip in a non-destructive manner. Ambient CO_2 and temperature levels during evaluations were 391 $\pm$15 $mg \cdot liter^{-1}$ and 35°C $\pm$1°, respectively.

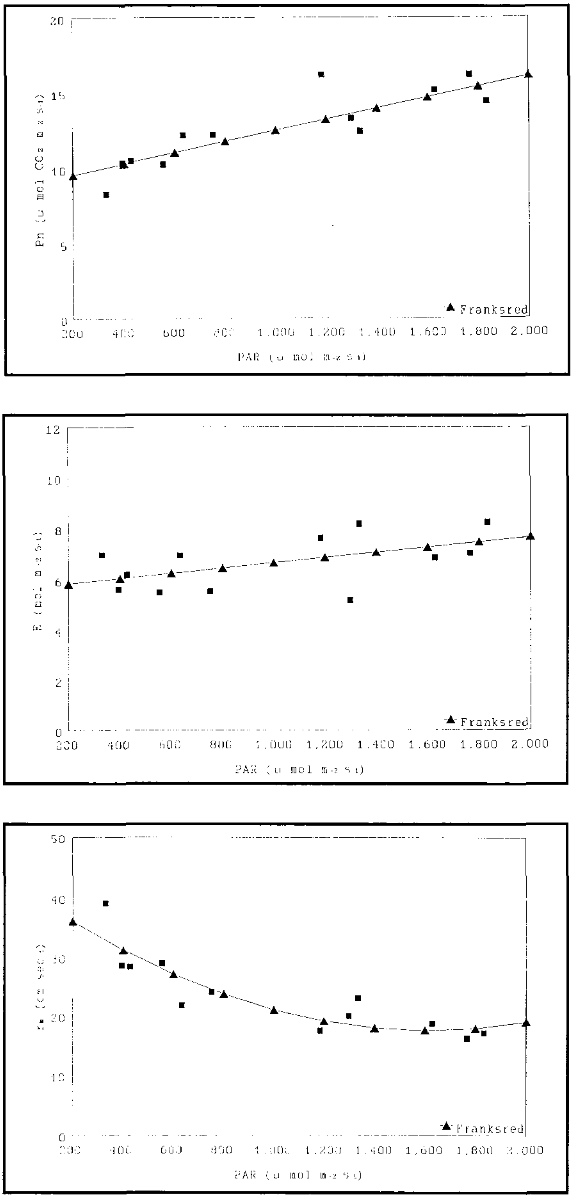
CO_2 exchange rate measurements, following Jurik (5), were taken from 10:00 am to 3:00 pm CST for six consecutive days in the last week of August and first week of September. Mesophyll resistance to CO_2 (r_m) was determined by C_i/Pn (11) and water use efficiency (WUE) by Pn/E measurements taken simultaneously.

Data were analyzed by regression to determine the relationship of each variable to PAR, whether it was linear, quadratic, or cubic based on probability and r^2 values for each individual cultivar (13). Differences were considered significant at $P = 0.05$.

Results and Discussion

As light intensity increased, the rate of net photosynthesis (Pn) and transpiration (E) increased linearly for 'Franksred' and 'October Glory' (Fig. 2 and Fig. 3). No light saturation point was attained for these cultivars under the conditions utilized in this study indicating continued

Fig. 2. Actual and predicted values for effect of photosynthetically active radiation (PAR) level on net photosynthesis (Pn) transpiration (E) and mesophyll resistance (r_m) to CO_2 of 'Franksred' red maple. Predicted regression lines followed by r^2 values and significance for the equations are as follows: Pn = 8.86818 + 0.00361x, r^2 = 0.42, P = 0.0001; E = 5.64104 + 0.001015x, r^2 = 0.14, P = 0.0179; r_m = 41.65603 -0.029823x + 0.000009245x^2, r^2 = 0.56, P = 0.0001.



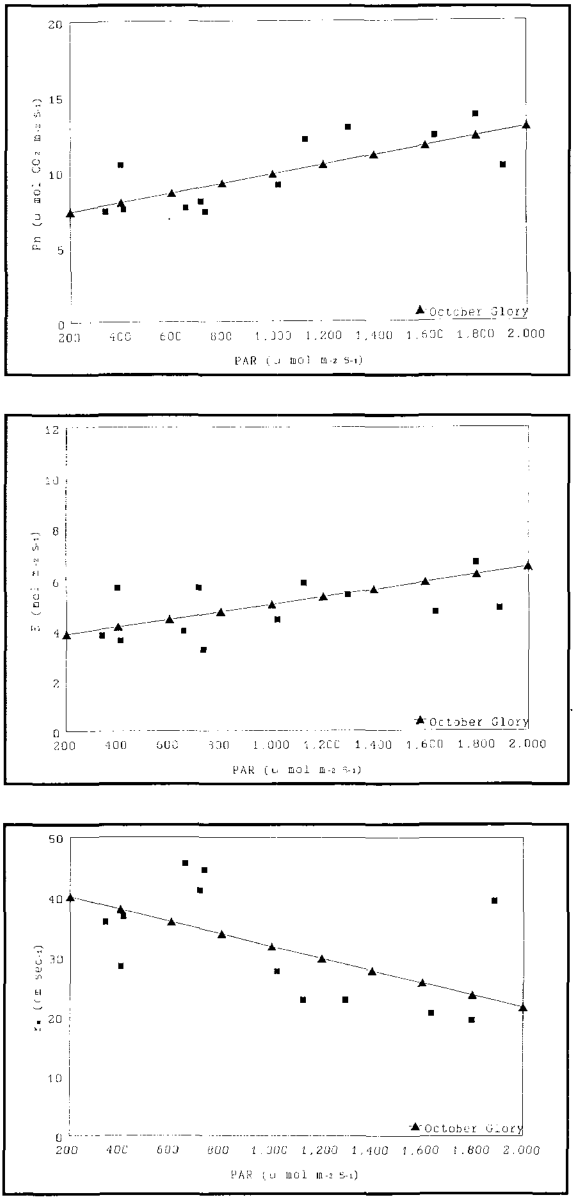
growth might be possible at higher PAR levels. Both of these cultivars may have the capacity to offset shorter growing seasons found at higher altitudes by utilizing the higher PAR levels typical of higher altitudes.

In contrast, Pn and E for 'Northwood' and 'Schlesingeri' increased quadratically with higher light intensity (Fig. 4 and Fig. 5--see pgs. 104 & 105). These data indicate predicted light saturation of Pn at PAR's of 1375 and 1350 µmol·m^{-2}·s^{-1} for 'Northwood' and 'Schlesingeri', respectively, under the conditions utilized in this study. Studies (1) estimate PAR, based on daily averages for total solar irradiance (K↓), as approximately 47% of K↓. Using data collected (Fig. 1) by the National Weather Service (D.M. Ihle, 1994 and D. Ruschy, 1994 personal communication), actual differences in K↓ for different latitudes were derived. Average K↓ levels in Auburn, Alabama for the month in which this study was conducted were 46% greater than K↓ recorded in northern Minnesota (Winton), the area from which 'Northwood' was selected. These results indicate that 'Northwood' and 'Schlesingeri' may be better suited to full sun locations in more northern latitudes than that in which this study was conducted. Also, these cultivars may have the ability to perform at their maximum photosynthetic capacity as understory trees in regions with high PAR.

Mesophyll resistance to CO_2 declined linearly as PAR increased for 'October Glory' (Fig. 3) but quadratically increased for 'Franksred', 'Northwood', and 'Schlesingeri' with predicted lows of 17.61 cm·sec^{-1} at 1600 PAR, and 16.45 cm·sec^{-1} and 16.36 cm·sec^{-1} at 1400 PAR, respectively (Figs. 2, 4, and 5). Mesophyll resistance was lowest for 'Northwood' and 'Schlesingeri' at PAR levels considered saturating for Pn, after which r_m began to increase. These data indicate that r_m for 'October Glory' was not limiting as PAR increased, but was becoming less resistant as light levels increased. This enhanced photosynthetic mechanism for r_m as PAR levels increased suggests 'October Glory' is the most adapted cultivar of the four selections in this study for high PAR environments.

No relationship was found between PAR and Cs for the four cultivars (data not shown). Maximum

Fig. 3. Actual and predicted values for effect of photosynthetically active radiation (PAR) level on net photosynthesis (Pn) transpiration (E) and mesophyll resistance (r_m) to CO_2 of 'October Glory' red maple. Predicted regression lines followed by r^2 values and significance for the equations are as follows: Pn = 6.71291 + 0.00307x, r^2 = 0.23, P = 0.002; E = 3.55897 + 0.001468x, r^2 = 0.18, P = 0.0072; and r_m = 42.089936 -0.010203x, r^2 = 0.13, P = 0.0241.



stomatal conductance for sugar maple was reported at PAR levels of 90 μmol·m^{-2}·s^{-1} (2). Reports by others discussing the lack of a relationship between PAR and Cs are summarized by Kozlowski et al. (8). The influence of PAR levels on Pn and E followed the same trend in each cultivar, therefore calculated WUE had no relationship to PAR for the four cultivars. Other studies have reported similar results (3, 15).

Conclusions

The rate of net photosynthesis for red maple cultivars 'Franksred', 'Northwood', 'October Glory', and 'Schlesingeri' is more closely associated with photosynthetic response to differing PAR levels than the influence of light on stomatal conductance. Measurements suggest that 'Northwood' and 'Schlesingeri' may be suitable as understory trees in areas of high light intensity. Performance of 'Franksred' and 'October Glory' is not limited by higher photosynthetically active radiation; which may allow improved performance in areas of high light intensity such as higher altitudes or lower latitudes. The enhanced response for r_m as light levels increase suggests that 'October Glory' is the most adapted cultivar in this study for high light environments. Adaptive ranges of red maple cultivars may be predicted by establishing light curves for Pn, E, and r_m.

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Fig. 4. Actual and predicted values for effect of photosynthetically active radiation (PAR) level on net photosynthesis (Pn) transpiration (E) and mesophyll resistance (r_m) to CO_2 of 'Northwood' red maple. Predicted regression lines followed by r^2 values and significance for the equations are as follows: Pn = 4.80619 + 0.017223x -0.000006270x^2, r^2 = 0.42, P = 0.0001; E = 5.248259 + 0.004630x - 0.00000151x^2, r^2 = 0.26, P = 0.0047; and r_m = 40.709790 -0.034418x + 0.000012208x^2, r^2 = 0.52, P = 0.0001.

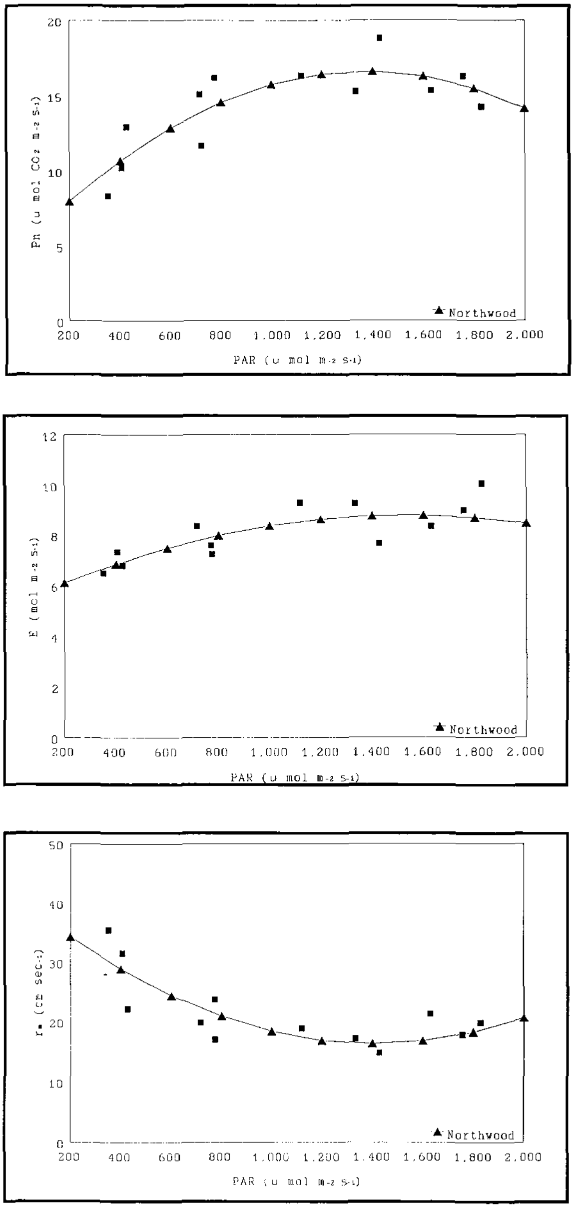

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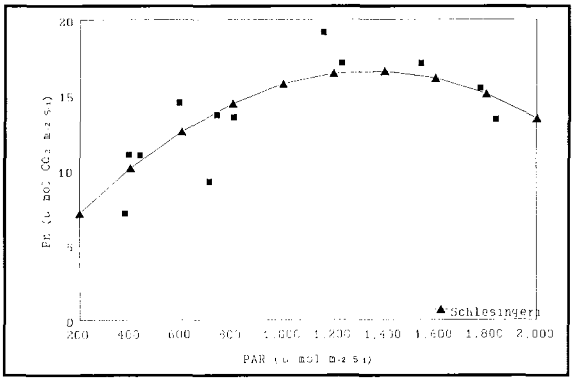
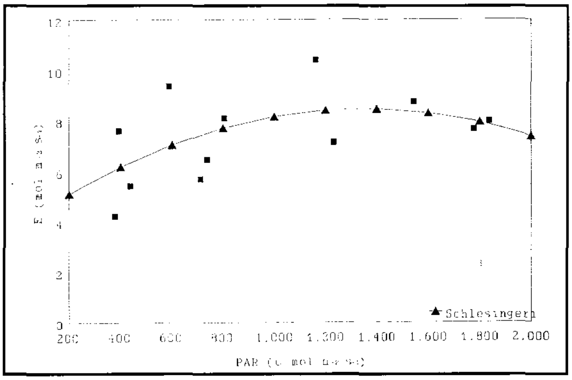
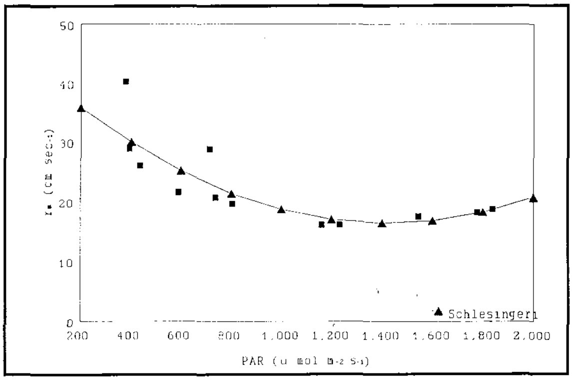
Fig. 5. Actual and predicted values for effect of photosynthetically active radiation (PAR) level on net photosynthesis (Pn) transpiration (E) and mesophyll resistance (r_m) to CO_2 of 'Schlesingeri' red maple. Predicted regression lines followed by r^2 values and significance for the equations are as follows: $Pn = 3.52937 + 0.01944x - 0.000007242x^2$, $r^2 = 0.45$, $P = 0.0001$; $E = 3.84974 + 0.006865x - 0.000002556x^2$, $r^2 = 0.20$, $P = 0.0164$; and $r_m = 42.688627 - 0.037077x + 0.000013049x^2$, $r^2 = 0.50$, $P = 0.0001$.







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Résumé. Les caractéristiques photosyn-thétiques d'un grand nombre de végétaux sont influencées par l'environnement lumineux dans lequel ils sont placés. Quatre cultivars d'érable rouge en contenants ('Franksred' - Red Sunset', 'Northwood', 'October Glory' et 'Schlesingeri') ont été évalués lors d'une étude sur la réponse à différents degrés de radiation photosynthétique active. La photosynthèse nette, la conductance stomatale, la transpiration et la concentration interne en gaz carbonique ont été déterminés sous différentes radiations. L'accroissement de la radiation a amené une augmentation linéaire de la photosynthèse nette et de la transpiration pour le 'Franksred' et le 'October Glory'. Au contraire, la photosynthèse nette et la transpiration pour le 'Northwood' et le 'Schlesinger' ont d'abord augmenté puis diminué avec l'accroisement de la radiation. Aucun lien n'a été trouvé, pour les quatre cultivars, entre l'efficacité d'utilisation de l'eau et la radiation. La résistance mésophyllique au gaz carbonique a diminué de façon linéaire avec l'augmentation de la radiation pour le 'October Glory'; elle a décru de façon quadratique pour les trois autres cultivars. Selon cette étude, 'October Glory' est le cultivar le mieux adapté des quatre aux environnements à forts taux de radiation. Les intervalles d'adaptation des cultivars d'érable rouge pourraient être prédits durant leur stade de développement en établissant des courbes de luminosité pour la photosynthèse nette, la transpiration et la résistance mésophyllique au gaz carbonique.

Zussammenfassung. Die photosynthetischen Eigenschaften einer großen Anzahl von Pflanzen werden durch die Lichtverhältnisse am Standort beeinflußt. In einer Containerstudie wurden vier Rotahorn-Kultivare (Acer rubrum 'Frankred', -'Red Sunset', -'Northwood', -'October Glory' und -'Schlesingeri') auf eine Reaktion hinsichtlich unterschiedlicher Grade photosynthetisch wirksamer Einstrahlung (PAR) untersucht. Nettophotosynthese, Leitfähigkeit der Stomata, Transpiration und die interne Konzentration von Kohlendioxid wurden unter verschiedenen PAR-Graden bestimmt. Mit steigender PAR war ein linearer Anstieg der Nettophotosynthese und Transpiration bei 'Franksred' und 'October Glory' *zu verzeichnen. Im Gegensatz dazu stieg die* Nettophotosynthese und Transpiration bei 'Nordwood' und 'Schlesingeri' erst an und fiel dann bei zunehmender PAR ab. Die effiziente Wassernutzung hatte bei allen Kultivaren keine Beziehung zur PAR. Der Widerstand des Mesophylls gegenüber Kohlendioxid nahm bei 'October Glory' bei ansteigender PAR linear und bei den drei anderen Kultiveren quadratisch ab. 'October Glory' ist allen in dieser Studie ausgewählten Kultivaren derjenige, der am besten an hohe PAR-Werte angepasst ist. Die Anpassungsraten von Rotahorn-Kultivaren können während der Entwicklungsstadien vorherbestimmt werden, indem man Lichtkurven für Nettophotosynthese, Transpiration, und den Widerstand des Mesophylls gegen Kohlendioxid vorgibt.